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NUTRITION, CONDITION AND RESISTANCE *

IN Florida orange trees treated with an assortment of major and minor elements including manganese, copper and zinc resisted frost during a severe winter much better than did trees treated with nitrogen, phosphate and potash alone: foliage damage resulted in some 90 per cent. of the latter whereas foliage damage in trees receiving the minor elements as well was only about 40 per cent. (1). The trial does not afford detailed information about the physiological function of the elements, nor does it make it possible to say whether the conferring of frost resistance was due to any one of the elements or—as seems more probable—to the interaction of some or all of them. Nevertheless, this demonstration that minor elements can act as a sort of "overcoat" for trees by giving them increased resistance against frost suggests that condition is bound up with the subtler aspects of nutrition. We have abundant evidence of the important influence of minor elements on the condition of animals; the example of cobalt in the nutrition of sheep is outstanding as supplying what from the fertilizer point of view may be regarded as an adequate explanation of the empirical observations of upland sheep farmers that sheep "do" much better on some hills than on others; the dividing line between "good" and "bad" fields or regions is sometimes very sharp, corresponding to a pronounced geological division between a cobalt-poor formation and one affording a sufficient cobalt supply.

Though the minor elements provide perhaps the most interesting examples of nutritional defects leading to poor condition in animals there are cases in which the resistance of plants to actively pathogenic agencies is increased by supplying minor or major elements. In some cases it is possible to suggest a partial explanation for the effectiveness of the remedy. Thus in Australia it has been observed that phosphatic manuring increased the resistance of cereals to wireworm attack. This was not due to any occult effect of phosphate or of impurities accompanying the fertilizer but to the fact that, the soil being deficient in phosphate, the plants made much better growth when phosphate was supplied. The root system being enlarged and the wireworm population remaining presumably the same, the

* From *Soils and Fertilizers*, 5, No. 2, 1942.

effect was to "dilute" the action of the worms to a degree which the plant could tolerate without suffering serious impairment of vigour.

C. Ellenby (2) has given a preliminary report of some manurial trials with potatoes designed with the idea that resistance to wireworm attack may be a function of nutrition. J. W. Hovy in Rhodesia has given evidence that quite small amounts of silver compound (the order being 500 grams per acre) gave practically complete control of the attack by one species of wireworm on tobacco (3). It is unlikely that this was due to a toxic action on the nematodes, and at present no better explanation than the vague ascription to soil "sickness" is available to account for some phenomena associated with sugar beet grown too frequently. There is also evidence that balanced manuring will promote resistance to the attack of other pests, but the rôle of plant nutrition in deterring small fauna from interfering with the integrity of plants is not easy to explain except in those places where the plant is obviously made unpalatable by uptake of an unusual element such as selenium.

There are diseases in which the activity of the pathogen is heightened by good nutrition of the host plant; the Verticillium wilt of cotton and tomato is one. In the case of Verticillium, spread of the disease to the soil and hence to a neighbouring plant does not occur until the roots decay: while life is abundant the pathogen remains internal to the plant, and presumably it makes its entrance, as do many viruses, only after the plant has been damaged so as to suffer a solution of its continuity or wholeness.

On the other hand, the odd procedure of manuring cactus pest plants was resorted to in parts of New South Wales so as to get an introduced predatory insect to attack them actively; cacti chlorotic through nitrogen deficiency were unacceptable to the insect, and either nitrogenous fertilizer had to be supplied or the nitrogen supply of the pest plants had to be assured by removal of competing trees (4).

The subject of the relationships between conditions and condition is obviously very complicated and cannot be satisfactorily dealt with in a brief review. From the manurial and soil points of view there is a good deal of evidence—often suggestive rather than conclusive—which collectively indicates that the matter might profitably receive more attention than has been hitherto given to it.

References

(1) W. W. Lawless and A. F. Camp.—*Proc. Fla. St. Hort. Soc.*, 53, 1940 (120-125).
(2) *Nature* 149, 1942 (50).
(3) *Nature* 144, 1939 (672).
(4) A. P. Dodd:—"The Control of Weeds." *Imperial Bureau of Pastures and Forage Crops, Herbage Bulletin* 27, 1940 (139-140).

SOIL-LESS CULTIVATION

A review of the recent progress in soil-less cultivation has recently been given by Prof. R. H. Stoughton (*J. Min. Agric.*, 49, 25 : 1942). In spite of many misconceptions and difficulties, steady progress has been made both in the laboratory and on small-scale semi-commercial installations, and a stage appears to have been reached when some reliable judgment can be formed on the question. Two types of systems are in use: (1) in which the plants are grown in a tank of nutrient solution with the roots immersed in a liquid medium; (2) where the permanent substratum is an inert material such as sand or gravel, to which nutrient solution is supplied at intervals. Carefully controlled trials have shown that in general the first of these is unsuitable for use in Great Britain, owing to the difficulty of securing adequate aeration for the roots, and the low light intensity. Far more promising results have been obtained with the second method, which may be considered under two main headings, namely, sand and sub-irrigation culture. In sand culture the plants are fed by watering on the nutrient solution from above, the surplus liquid draining away. Tomatoes, chrysanthemums, lettuce and a wide range of vegetables gave very satisfactory crops under these conditions, and promising results have been obtained with carnations using a slightly modified and simplified technique.

The disadvantages of the system, however, are the care needed in the control of the moisture content of the medium, and wastage of materials through drainage, but these are to some extent offset by the small cost of the outlay compared with the sub-irrigation method. In the latter case, the nutrient solution is pumped at intervals from below into the growing-tank until the gravel is flooded to the top, the pump is then shut off and the liquid flows back by gravity to the supply tank. The watering and feeding can thus be made almost automatic, the aeration of the medium is excellent and considerable economy in fertilizer materials is effected. Further, chemical sterilization of the gravel is easily carried out. To meet the criticism that soil-less cultivation results in crops of lower nutritional value, chemical analysis of the carbohydrate, protein, inorganic constituents and vitamin C content were carried out. No significant differences could be established between plants grown in gravel and those grown in soil. Experiments are now in progress at the University of Reading, under a grant from the British Electrical and Allied Industries Research Association, to test, among other things, the effect of heating the solution in the sub-irrigation culture of tomatoes. Work is also proceeding on the chemical testing of the solution by simple colour tests, so that its composition may be readily controlled according to the requirements of the crops.—(*Nature*, Vol. 150, No. 3797).

WITCHES' BROOM DISEASE INVESTIGATIONS

II Notes on the Susceptibility of I.C.S. Selections at River Estate to Witches' Broom Disease of Cacao

BY

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Introduction

In July, 1940 observations on susceptibility to witches' broom disease were started on the two, three and four year old I.C.S. clones at River Estate. Somewhat contrary to expectations, highly significant results have been obtained indicating that some clones are more susceptible to the disease than others. It must be remembered however, that these trees are very young and that at present there is no evidence as to whether this difference in susceptibility will be maintained on mature trees, or whether the pods will show the same resistance as the vegetative buds and cushions. Furthermore none of these clones is immune to the disease, or even highly resistant; clones described here as 'resistant' merely show a greater degree of resistance than those with which they are compared in these trials.

Witches' broom disease is severe at River Estate and for the last two years these young trees have been heavily attacked. The four year old trees have averaged over thirty brooms a year, many of them very large, and many of the trees belonging to susceptible clones have produced between fifty and one hundred brooms in a year. The removal of these brooms and the consequent loss of healthy twigs and branches must appreciably check young trees.

Two methods have been used for estimating the susceptibility of clones. In the first, thirty-two trees of each clones were used, and all brooms, both fan and cushion were removed at the end of each month. At the end of twelve months and after two years the results were analysed statistically. From the first year's results it was noted that 80 per cent. of the annual total of brooms was produced in the months of January, February and March, and a simpler technique was therefore devised. It was considered that if all the trees were cleared of brooms in December, a single counting made during March would give nearly as good results as the method of monthly countings, especially if a larger number of trees was included in the experiment. This proved to be so and in March, 1942 highly significant data were obtained on the relative susceptibility of a further ten clones. An analysis of this kind made on these trees in March, 1941, has already been published (Baker, Crowdy and Thorold, 1941). Here the clonal differences were masked by the drift of infection from an adjacent heavily infected area. This reservoir of infection was removed in 1941 and results obtained in March, 1942, indicate that the drift of infection across the field has also disappeared.

The number of brooms removed over a period of two years in the first six clones is shown in Tables I and II, and the statistical results are summarised in Tables III and IV.

Table I

Brooms Removed from July, 1940 to June, 1941 from 192 trees

Clone	Fan Brooms	Cushion Brooms	Total Brooms
I.C.S. 1 ...	496	160	656
3 ...	680	305	985
4 ...	635	595	1,230
5 ...	345	391	736
6 ...	495	54	549
8 ...	416	79	495
	3,067	1,584	4,651

Table II

Brooms Removed from July, 1941 to June, 1942 from 192 trees

Clone	Fan Brooms	Cushion Brooms	Total Brooms
1 ...	597	172	769
3 ...	1,001	760	1,761
4 ...	1,097	515	1,612
5 ...	544	349	893
6 ...	718	108	826
8 ...	710	51	761
	4,667	1,955	6,622

The two years results are remarkably consistent and indicate that I.C.S.1, 6 and 8 are more resistant than I.C.S.3 and 4. I.C.S.5 occupies an intermediate position as although it is as good as I.C.S.1, 6 and 8 on fan brooms it appears to be more susceptible to cushion brooms.

In March, 1942 the second method was used on a further ten clones (I.C.S. 1 is present as a standard) with the results shown in Tables V and VI. The data presented in Table VI were obtained from trees a year younger than those in Table V and the results are therefore of less value.

From Table V it would appear that on fan brooms alone I.C.S. 53 is significantly worse than the remainder which cannot be separated from

Table III
Set I, Summary of Results, July, 1940 to June, 1941

Fan Brooms			Cushion Brooms			Total Brooms		
Clone.	Mean Brooms per Tree	Difference	Clone	Mean Brooms per Tree	Difference	Clone	Mean Brooms per Tree	Difference
I.C.S. 4	24.8		4	23.8		4	48.5	
		1.1			6.9**			13.9**
3	23.7		5	16.9		3	34.6	
		6.3**			6.1**			4.2
6	17.4		3	10.8		5	30.4	
		1.0			5.3*			8.5*
1	16.4		1	5.5		1	21.9	
		0.3			2.2			2.5
8	16.1		8	3.3		8	19.4	
		2.6			1.4			0.1
5	13.5		6	1.9		6	19.3	
Critical difference at 1% point=5.0			Critical difference at 1% point=5.6			Critical difference at 1% point=8.8		

Table IV
Set I, Summary of Results, July, 1941 to June, 1942

Fan Brooms			Cushion Brooms			Total Brooms		
Clone	Mean Brooms per Tree	Difference	Clone.	Mean Brooms per Tree	Difference	Clone	Mean Brooms per Tree	Difference
4	39.6		3	24.4		4	58.7	
		7.3			5.3			2.0
3	32.3		4	19.1		3	56.7	
		7.6			4.9			19.7**
8	24.7		5	14.2		5	37.0	
		1.9			8.9*			11.5
5	22.8		1	5.3		8	26.5	
		0.3			2.0			0.7
6	22.5		6	3.3		6	25.8	
		3.8			1.5			1.8
1	18.7		8	1.8		1	24.0	
Critical difference at 5% point=8.4			Critical difference at 5% point=7.3			Critical difference at 1% point=17.8		

** Significant at 1% point. * Significant at 5% point.

Table V
Set II, Summary of Results, March, 1942

Fan Brooms			Cushion Brooms			Total Brooms		
Clone	Fan Brooms per Tree	Difference	Clone	Cushion Brooms per Tree	Difference	Clone	Total Brooms per Tree	Difference
53	9.7		16	3.0		53	12.0	
		2.9**			0.6			2.27*
16	6.8		53	2.4		16	9.8	
		0.2			0.3			1.5
22	6.6		45	2.1		45	8.3	
		0.4			0.6			1.3
45	6.2		1	1.5		1	7.0	
		0.7			1.0*			0.1
1	5.5		7	0.5		22	6.9	
		0.3			0.2			1.2
7	5.2		22	0.3		7	5.7	
Critical Difference 1% point=1.9 5% point=1.4			Critical Difference 1% point=1.1 5% point=0.8			Critical Difference 1% point=2.4 5% point=1.8		

**Significant at 1% * Significant at 5%

each other. On cushion brooms alone I.C.S. 7 and 22 are the best, I.C.S. 1 intermediate, and I.C.S. 16, 45 and 53 are the worst. On total brooms I.C.S. 1, 7 and 22 appear to be the best with I.C.S. 16 and 45 intermediate and I.C.S. 53 definitely the worst. It should be noted however that I.C.S. 7 is very backward and may appear better than it should for that reason. Similarly I.C.S. 53 is very vigorous and may appear worse than it should as some of its trees are already very large.

From Table VI, judging by fan brooms, cushion brooms and total brooms I.C.S. 60 is very susceptible, I.C.S. 12 intermediate and I.C.S. 1, 2, 9 and 98 are least susceptible. I.C.S. 2 is backward and severely attacked by cacao beetles and may therefore not be as good as the results indicate.

A rough grading of the sixteen clones made in March, 1942 appears in Table VII. The results indicate that I.C.S. 2, 5 and 7 are backward, I.C.S. 2 and 5 being in addition severely damaged by cacao beetles; I.C.S. 3, 4, 16, 53 and 60 will probably be useless in areas where Witches' broom disease is severe, and I.C.S. 1, 6, 8, 9, 22 and 98 are worth further trial.

In conclusion it must be reiterated that these results have been obtained from young trees and that no account has been taken of pod resistance. They may therefore require considerable modification in the light of future experience.

Table VI

Set III, Summary of Results, March, 1942

Fan Brooms			Cushion Brooms			Total Brooms		
Clone	Fan Brooms per Tree	Difference	Clone	Cushion Brooms per Tree	Difference	Clone	Total Brooms per Tree	Difference
60	8.0		60	4.6		60	12.6	
		2.8**			2.9**			5.7**
12	5.2		12	1.7		12	6.9	
		2.1*			1.2*			3.4*
9	3.1		1	0.5		1	3.5	
		0.1			0.4			0.3
1	3.0		2	0.1		9	3.2	
		0.2			0.1			0.3
98	2.8		9	0.04		98	2.9	
		0.9			—			0.8
2	1.9		98	0.01		2	2.1	
Critical Difference 1% point=2.5 5% point=1.9			Critical Difference 1% point=1.6 5% point=1.2			Critical Difference 1% point=3.6 5% point=2.7		

** Significant at 1%

* Significant at 5%

Table VII

Grading of I.C.S. Clones for Witches' Broom Disease Resistance, March, 1942, Sets I, II and III

Fan Brooms				Cushion Brooms				Total Brooms			
Good I.C.S.	Fair I.C.S.	Poor I.C.S.	Bad I.C.S.	Good I.C.S.	Fair I.C.S.	Poor I.C.S.	Bad I.C.S.	Good I.C.S.	Fair I.C.S.	Poor I.C.S.	Bad I.C.S.
1	2	12	3	6	1	5	3	1	2	12	3
6	5	—	4	8	12	45	4	6	5	16	4
8	7	—	53	22	—	53	60	8	7	—	53
45	—	—	60	7	—	16	—	9	45	—	60
22	—	—	—	98	—	—	—	22	—	—	—
16	—	—	—	9	—	—	—	98	—	—	—
98	—	—	—	2	—	—	—	—	—	—	—
9	—	—	—	—	—	—	—	—	—	—	—

STUDIES IN OIL FORMATION IN THE V.135 AND M.S.I. VARIETIES OF SEA ISLAND COTTON IN ST. VINCENT, B.W.I.

BY

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Introduction

Cotton seed oil is one of the most important vegetable oils in the West Indies and is a by-product of the Sea Island cotton industry. A good edible grade is produced by the St. Vincent Government Cotton Ginnery, and is consumed locally for cooking purposes. A low grade of soap is also produced from the refinery residues.

Statistics in regard to the local production of refined cotton seed oil, and also the imports of this and other types of edible oils and fats during the period 1931-40 show that local production has increased greatly in recent years, while imports have declined. The general trend has been accentuated by war time difficulties, but St. Vincent oil accounted for about half (by value) of the Colony's annual consumption of edible fats and oils in 1937 and 1938. It is evident therefore that the production of cotton seed oil is of very great importance to the Colony.

Little was known of either the development or the final content of oil in Sea Island cotton seed, and the studies here reported were undertaken to provide this information as a starting point for better chemical control of the oil recovery process.

Most of the work on the development of oil in cotton seed has been performed in the United States of America. This work, for the most part, has been carried out by the following investigators, namely, Garner, Allard, and Foubert (1914), White (1915), Gallup (1928), and Gallup and Caskey (1931), Cooper and Mitchell (1932), and O'Kelly, Hull, and Geiger (1933). Experiments, however, have also been carried out in Russia by Lonzinger and Raskina (1931) and Zakoshchikov, Leonov and Raskina (1933), cited in *Chemical Abstracts* (1932) and (1934) respectively, as well as in South Africa by Rainey (1939-40).

Experimental Work

The experiments were carried out during the 1938-39 and 1939-40 crop seasons. Originally they were started in collaboration with Mr. F. A. Squire, Entomologist for Cotton Pests, in St. Vincent (1936-39), who was mainly interested in tracing the effect of the development of oil on the nutrition of the Pink Boll Worm (*Platyedra gossypiella*, Saund.). Squire (1940) has since published a paper on this aspect of the work. Later, however, the writer extended the scope of these investigations to include the effects of manuring on oil formation, and repeated much of the work previously done.

Two varieties were included in the experiments, V.135, the commercial superfine cotton of St. Vincent, and M.S.I., the "Sea Island Ordinary" variety grown in the Leeward Islands, B.W.I.

During the 1938-39 crop season, all seed samples examined were obtained from a combined varietal and manurial trial laid down at Arnos Vale Estate by the St. Vincent Agricultural Department (1939). The comparisons involved were the above varieties together with fertilizer dressings resulting from combinations of sulphate of ammonia (3 cwt. per acre), superphosphate (3 cwt. per acre), and sulphate of potash (2 cwt. per acre). In the following crop season, seed samples of the two varieties were obtained from experimental plots at the Experiment Station.

Effect of Manuring on the Oil Content of V.135 Seed

(1) *Mature Seed*

Samples of mature V.135 seed were obtained after ginning from the total pickings of seed cotton from the plots of the cotton experiment at Arnos Vale. Representative samples of seed from each plot were obtained by a system of mixing and quartering, commencing with the entire quantity of seed obtained per plot and continuing the operation until a sample of about 150 grams remained. These samples were heated in an electric oven at 100°C. until their moisture contents had been reduced to about 5 per cent. The dried seed was then ground to a fine meal in a hand mill, care being taken to obtain as fine a meal as possible, because, according to Lockwood (1938), fineness of subdivision is essential for efficient oil extraction. The dried meal was stored in air-tight glass containers, and analysed a short time after for percentage oil content by the method recommended by the Association of Official Agricultural Chemists (1935). After weighing, the refractive indices of the ether extracts were determined by means of a Zeiss refractometer, and the readings were corrected to 25°C. by the temperature coefficients of Kanthack-Goldsmith (1921). Individual plot samples were tested separately, thus permitting a statistical analysis of the results.

The agricultural data, which were analysed statistically by the Agricultural Department, St. Vincent (1939), showed that the nitrogenous treatment gave large and significant increases in yield of seed cotton. Yields of oil (in gallons per acre) were therefore calculated from yields of seed per plot and the moisture and oil contents of the seed.

In Table I the treatment means are given for the percentage oil content of the seed on a dry matter basis, the refractive index of the oil, and the yields of oil per acre.

Manuring with nitrogen caused a significant decrease in the oil content of the seed. This effect tends to be confirmed by the results obtained with developing seed presented in the following section; and is in line with the results of the investigations with American Upland cotton by Garner *et al* (1914).

It is worth noting that, in the absence of phosphate, potash produced an increase in oil content that was very nearly significant. This result, however, is not confirmed with the developing seed. With American Upland cotton the investigations of O'Kelly *et al* (1933), indicate that the oil content of the seed was increased by applications of potash. In view of this, it would appear desirable that further experiments should be carried out with V.135 seed in order to obtain more information on the potash effect.

The effect of manuring on total yield of oil differed from that on oil content. Nitrogen, as before, was the only treatment affecting total yield of oil, but the lower oil content of the nitrogen-treated plots was more than balanced by the increased yields of seed, and consequently the total yield of oil was considerably and significantly increased.

Differences in the refractive index of the oil were very small and of no real importance.

(II) *Developing Seed.*

An attempt was made to determine the effect of manuring on the formation of oil in the developing V.135 seed. To this end, freshly opened flowers on the experimental plots at Arnos Vale were tagged at approximately weekly intervals during the period 17.12.38 to 4.2.39. Samples of bolls developing from these flowers were picked when 27, 34, 39, 47, 52 and 56 days old. It had originally been planned to sample individual plots as was done in the case of mature seed, but, owing to rather heavy boll-shedding, this was found to be impossible. In the case of seed 39, 47, 52 and 56 days old, equal numbers of bolls from each of the replicates were combined, so that representative samples were obtained for each manurial treatment; this procedure, however, precluded the complete statistical analysis of the results. With seed 27 and 34 days

Table I

Treatments.	Treatment Means.			Treatments.	Treatment Means.	
	Per cent. Oil.	Refractive Index.	Oil per Acre Imp. glns.		Per cent. Oil.	Oil per Acre Imp. glns.
Control	27.15	1.4772	9.29	N	26.26	16.17
N	25.61	1.4773	15.21	No N	27.80	10.02
P	27.95	1.4780	10.41	P	26.92	13.62
K	28.65	1.4780	10.22	No P	27.15	12.57
NP	25.87	1.4768	15.01	K	27.42	13.71
NK	27.18	1.4775	15.57	No K	26.65	12.48
PK	27.47	1.4769	10.17			
NPK	26.39	1.4784	18.87			

Table II

Due to	Degrees of Freedom.	Per cent. Oil Content.			Yield of Oil.		
		Variance.	$\frac{1}{2}$ Log$_e$ of Variance $\times 10$	Z	Variance.	$\frac{1}{2}$ Log$_e$ Variance.	Z
N	1	14.25	2.4797	1.3594	330.78	2.9007	1.8371
P	1	.31			9.75		
K	1	3.58	1.7890	.6687	13.05		
NP	1	.01			2.34		
NK	1	.43			6.72		
PK	1	3.44	1.7691	.6488	3.01		
NPK	1	.32			12.18		
Blocks	2	1.85			4.61		
Error	14	.94	1.1203		8.39	1.0636	
Total	23	17.04			21.94		

$N_1=1$; $N_2=14$; $Z=.7630$ at 5 % P.

old, even the manurial treatments had to be ignored, and equal numbers of bolls from all plots were combined.

The freshly picked bolls were immediately brought to the laboratory and the seeds extracted and cleaned of lint. The seed was then heated, dried and converted into a fine meal and the oil content determined in the same manner as with the mature seed. A summary of the more important features of these analyses is presented in Table III.

Table III

Age of Seed days.	Average per cent. Oil Content of the Seed on a Dry Matter Basis.					
	N	No N	P	No P	K	No K
39	20.82	21.48	20.93	21.37	20.46	21.84
47	23.42	23.77	23.47	23.72	23.67	23.52
52	26.17	27.56	26.83	26.90	26.66	27.08
56	26.61	27.56	26.64	27.53	27.11	27.06

An inspection of these results reveals that nitrogenous manuring tended to lower the oil content of the seed throughout the period of its development. This nitrogen effect has already been confirmed with mature V.135 and Upland seed.

Potash and phosphate appeared to have very little effect on oil formation.

Rate of Oil Formation in Developing Seed

During the 1938-39 and 1939-40 crop seasons, the rate of oil formation on developing V.135 and M.S.I. seed was determined.

In 1938-39, this was traced on representative samples of M.S.I. seed ranging from 31 to 56 days old obtained from the plots of the cotton experiment at Arnos Vale. Manurial treatments were ignored, and equal numbers of bolls from all plots were combined. In every case, samples representative of the different age groups comprised 72 bolls. The tagging of the flowers, the treatment of the seed, and the analysis for oil on meal obtained therefrom, were carried out in the same manner as before. The average oil content of the V.135 seed, ignoring manurial treatments for the various age groups in the developmental series (*vide* Table III) also indicated the rate of oil formation in this variety; these data, along with the results obtained for seed 27 and 34 days old, are therefore presented below for comparison.

During the 1939-40 crop season, the studies on the rate of oil formation were repeated on samples taken from V.135 and M.S.I.plots at the Experiment Station. These plots had previously received dressings of sulphate of ammonia (about 3 cwt. per acre), and sulphate of potash (1-1½ cwt. per acre). About 1,500 flowers of each variety were labelled during the period 3.11.39 to 12.1.40, and 100 bolls of each variety maturing from these flowers were picked when 15 days old and every 5 days thereafter until the age of 65 days was reached. The following determinations were carried out on these samples: the percentage of bolls which had split, the moisture and oil contents of the seed, and the refractive index of the oil in the seed. The treatment and analysis of the seed for oil were performed as before. The refractive index of the oil was determined on the other extracts after weighing.

The results of the experiments carried out during the 1938-39 crop season at Arnos Vale are presented below in Table IV and graphically presented in Fig 1.

Table IV

Age of Seed days.	Per cent. Oil Content of the Seed on a Dry Matter Basis.	
	V. 135	M.S.I.
27	4.55	—
31	—	7.01
34	9.73	—
37	—	18.21
39	21.15	—
44	—	24.61
47	23.59	—
52	26.87	—
56	27.08	27.55

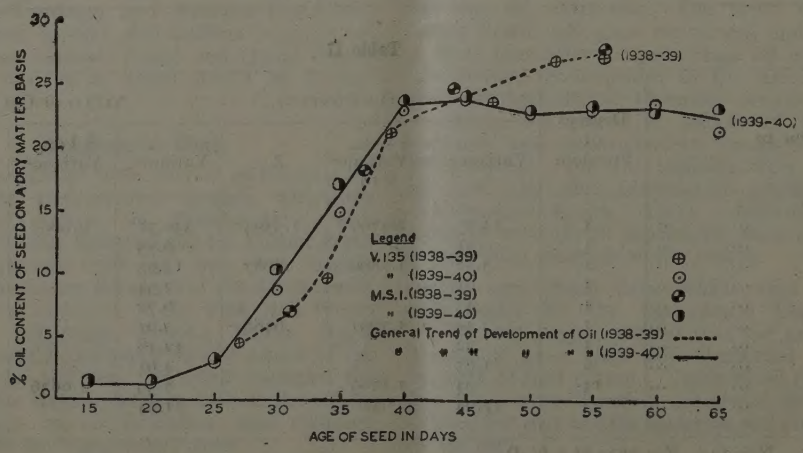

FIGURE 1 — DEVELOPMENT OF OIL IN SEA ISLAND COTTON

In Table V are given the results obtained in the 1939-40 crop season at the Experiment Station.

The moisture content of both varieties decreased with increasing age of seed. The decrease following boll split was the normal drying out of the mature and dormant seed.

Bolls commenced to split in both varieties between the 40th and 45th day. The entire period involved was shorter in M.S.I. than in V.135, all M.S.I. bolls having split by the 55th day when 23.7 per cent. of the V.135 remained unopened. Commencement of splitting of bolls apparently varies considerably with different varieties. Gallup (1928) found with the American Upland variety Oklahoma Triumph 44 that "none of the bolls had opened until after the fortieth day and in the collection made on the forty-sixth day only 10 in 100 had opened". Rainey (1939-40) reported that, with the variety 052, a strain of U4, cultivated at Barberton, South Africa, splitting took place in the 10th week.

At the commencement of the splitting of the bolls, oil formation in both varieties had practically ceased. This finding is in line with the results obtained by Gallup (1928); and also by Rainey (1939-40).

In regard to the rate of development of oil, there was a period when this was intense, extending, in the case of the results for Arnos Vale in 1938-39, from the earliest age group to approximately the 45th day. In the more extensive data of the following crop year, this period was shown to extend from about the 25th to the 40th day.

The rate of oil formation in the two varieties was practically the same. It should be noted, however, that the oil content of mature seed was higher in 1938-39 at Arnos Vale than at the Experiment Station in 1939-40. This may be due either to climatic or soil differences. In this connection, Garner *et al* (1914) found that, "under practical conditions, climate is a more potent factor than soil in controlling the oil content of cotton seed". Rather wide variations in yield of oil for Upland varieties grown in the principal cotton producing areas in the United States of America during the period 1914-19 were found by Creswell and Bidwell (1921).

A comparison of oil formation in the Sea Island varieties and in the Upland varieties featuring in the investigations of Gallup (1928), and Caskey and Gallup (1931) reveals that the grand period of oil development was some ten days later in the former than in the latter. It should be noted however, that the average oil content of mature Sea Island seed for the 1938-40 seasons was somewhat higher than that of the Upland varieties examined by the above-mentioned investigators, as well as by Harrington (1928). In this connection, Botkin (1929) reports that the seed of the Acala strain grown in New Mexico, U.S.A., during the period 1925-27 had an average oil content of 24.47 per cent., and suggests that data from other regions indicates that the New Mexico seed is highest in oil content. It appears therefore that Sea Island cotton has on the whole a rather higher oil content than American Upland.

The ether extracts of both strains 15 and 20 days old were solid at room temperature, and no refractive indices were obtained. Extracts 25 to 65 days old, however, were liquid and readings were easily obtainable. Also in general after the 30th day of age, the readings appeared to indicate a slight increase in the refractive index of the oil with an increase in the age of the seed. The refractive index of the oil of mature V.135 seed was 1.4773; this reading differed only slightly from that of mature M.S.I. seed which was 1.4791 (both readings at 25°C.).

The variation in the refractive index of the oil of these two Sea Island varieties, however, was somewhat greater than that between 73 varieties and strains of American Upland cotton as reported by Harrington (1928), who found a variation between the limits of 1.4738 and 1.4740 at 20°C.

Table V

Age Seed Days.	% Moisture in Seed.		% Bolls Which had Split.		% Oil Content of Seed.				Refractive Index of Oil in the Seed.	
					V.135		M.S.I.			
	V.135	M.S.I.	V.135	M.S.I.	Referred Original Weight.	Referred Oven Dry Weight.	Referred Original Weight.	Referred Oven Dry Weight.	V.135	M.S.I.
15	79.1	77.7	0	0	0.28	1.32	0.31	1.41	—	—
20	76.5	77.8	0	0	0.23	0.98	0.30	1.33	—	—
25	74.8	76.3	0	0	0.70	2.78	0.75	3.17	1.4763	1.4764
30	72.0	73.6	0	0	2.42	8.66	2.72	10.31	1.4737	1.4724
35	69.9	65.9	0	0	4.45	14.79	5.78	16.96	1.4737	1.4744
40	61.1	57.9	0	0	8.89	22.86	9.95	23.63	1.4754	1.4764
45	52.0	51.0	26.9	23.1	11.28	23.51	11.74	23.96	1.4750	1.4771
50	41.9	31.8	70.6	93.6	13.20	22.72	15.52	22.75	1.4745	1.4778
55	40.1	12.0	76.3	100.0	13.77	22.98	20.33	23.10	1.4759	1.4787
60	12.9	10.3	100.0	100.0	20.41	23.43	20.40	22.74	1.4763	1.4787
65	9.6	10.5	100.0	100.0	19.24	21.28	20.67	23.10	1.4773	1.4791

From the above it will be seen that there was very little difference between the refractive index of the oil of mature Sea Island and Upland seed.

Summary

Data are presented showing the importance of the production of cotton seed oil in St. Vincent, B.W.I.

Experiments were carried out during the 1938-40 crop seasons to determine the effect of manuring on oil formation and the rate of development of oil in the V.135 and M.S.I. varieties of Sea Island cotton.

Results with manuring showed that nitrogen affected both the oil content and the total yield of oil of mature V. 135 seed, the former being decreased and the latter increased significantly. The nitrogen effect on oil content was confirmed with developing V.135 seed; and was also in line with the results of American investigators on Upland cotton. Potash and phosphate produced very little effect on mature or developing V.135 seed.

In tracing the rate of development of oil in the two varieties the following results were obtained. Moisture content decreased with an increase in the age of the seed; the decrease following boll split being the normal drying out of the mature seed. There was a period of intense oil formation in both varieties extending from about the 25th to the 40th day; this grand period of oil formation occurred some 10 days earlier in an Upland variety. Splitting of the bolls commenced in both varieties between the 40th and the 45th day; the entire period occupied about 15 days for M.S.I as compared with about 20 days for V.135. At the commencement of the splitting of the bolls oil formation had already ceased. The rate of oil formation in the two varieties was practically the same, although there was a seasonal variation in the oil content of both varieties. The oil content of mature Sea Island seed was on the whole higher than that of American Upland seed. After the 30th day of age the refractive index of the oil in the seed showed a slight increase with an increase in the age of the seed. There was little difference between the refractive index of the oil of mature Sea Island and Upland seed.

Acknowledgment

The work here reported was carried out in the Agricultural Department, St. Vincent, B.W.I. Grateful acknowledgment is made to Mr. F. A. Squire, formerly Entomologist for Cotton Pests, St. Vincent, with whose collaboration the study was started; to Professor F. Hardy, Imperial College of Tropical Agriculture Trinidad, for advice and criticism on certain chemical aspects of the work; and to Messrs. C. K. Robinson, Agricultural Superintendent, H. L. Manning, Cotton Officer, and G. A. Grant, formerly manager of the Government Cotton Ginnery, St. Vincent, for their assistance.

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STUDIES ON AERATION OF CACAO SOILS IN TRINIDAD (II)

BY

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INTRODUCTION

BY F. HARDY
(*Professor of Chemistry and Soil Science*)

In the first article of this series (1), the *quantitative* aspect of aeration in a fine-sandy cacao soil occurring at River Estate, North-West Trinidad, was considered, and experimental evidence was adduced to demonstrate that this soil, although regarded as a free-draining type, is too compact and contains too little air-space, so that it is likely to impede the circulation of water and soil-gases, particularly during periods of heavy and fairly continuous rainfall, and root asphixiation may thus ensue. Actually the soil below the 24-inches depth at this site appears to be completely devoid of air for a large part of the wet season, and even the surface 6-inches layer shows only "average" values for air-space (namely, between 10 and 5 per cent.) during wet weather. It would be interesting to know the composition of the gas occupying this limited amount of air-space, since, if the soil-gas is deficient in oxygen, the poor condition of aeration would be still further aggravated. Accordingly, an attempt was made by Dr. Vine to obtain some idea of soil-gas composition at different times of the year for this soil. Later, the investigation was extended by Mr. Thompson to certain other sites and soil-types for purposes of comparison.

PART II

SOIL-AIR COMPOSITION IN CERTAIN CACAO SOIL-TYPES IN TRINIDAD

(A) RIVER FINE SAND: RIVER ESTATE

BY H. VINE, PH.D. (London)
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The following section describes preliminary studies of the qualitative aspect of soil aeration carried out during 1938-1939 at River Estate (the Trinidad Government Cacao Experimental Station), on the same site as that where the investigations described in the last article (Part I) were made. The experimental work was designed firstly to test certain methods of soil-gas sampling described in literature, and secondly to procure data for soil-gas composition (with respect to oxygen and carbon-dioxide contents) for the particular soil-type represented by the cacao field under consideration, namely River Fine Sand (2).

Experimental Work

EXPERIMENT 1.

This was designed to compare the two methods of soil-gas sampling devised respectively by Russell and Appleyard (3) and by Boynton and Reuther (4). The results obtained are presented in Table I; they refer to the surface 4-inch layer of soil, the gas content of which was sampled separately at the same time by the two different procedures. The gas samples withdrawn in the field were transported in 15 cc. glass tubes to the laboratory, where they were analysed in a standard Haldane absorption apparatus.

Conclusion.—It is considered that the numerical differences between the data obtained by the two methods are insignificant, and that results obtained by either method are comparable with those obtained by the other. This is an important finding because, although Russell and Appleyard's method was used in our early experiments, it was replaced later by the more convenient method devised by Boynton and Reuther. It is important to know that the results obtained by these two methods are comparable.

EXPERIMENT 2.

The object of this experiment was to determine the variation in the composition of soil-gas at various times and places within a cacao field, under varying soil moisture conditions. The samples of soil-gas for analysis were collected on five separate occasions during the wet season of 1939 (but not, as it happened, during the rainiest part), and on one occasion in the middle of the dry season of 1940. The method used for sampling was Russell and Appleyard's "sampling-tube" method. Gas samples were collected mostly from the surface 4-inch layer of soil, but in some instances, samples were also collected from layers below, namely, 4 to 8 inches, and 8 to 12 inches. In order to withdraw soil-gas from the lowest layer, reduced pressure, equal approximately to half an atmosphere, had to be applied. On most occasions, no gas could be withdrawn, even under greatly reduced pressure, from the lowest layer of soil, presumably because of its high moisture content.

The results obtained are set out in Table II, where they are arranged in order of decreasing oxygen content of soil-air, which is seen to be

Table I

Comparison of Two Methods for sampling Soil-Gas

No. of trial	Sampling tube method of Russell and Appleyard		Sampling well method of Boynton and Reuther		Differences between means	
	Oxygen	Carbon-dioxide	Oxygen	Carbon-dioxide	Oxygen	Carbon-dioxide
	(Per cent.)				(Per cent.)	
(1)	8.7	6.3	10.3	5.7		
	9.1	6.5	9.3	6.7		
Means	8.9	6.4	9.8	6.2	+0.9	—0.2
(2)	8.3	6.5	—	—		
	10.0	6.6	9.6	7.0		
	9.9	6.4	—	—		
Means	9.4	6.5	9.6	7.0	+0.2	+0.5
(3)	18.0	3.6	19.9	1.3		
	15.9	5.7	16.3	5.2		
Means	17.0	4.7	18.1	3.3	+1.1	—1.4
(4)	20.3	0.9	18.1	4.0		
	19.8	1.4	16.7	5.5		
Means	20.1	1.2	17.4	4.8	—2.7	+3.6
(5)	18.0	3.2	19.6	1.5		
	15.4	5.3	17.7	3.3		
	16.3	4.7	16.3	4.9		
	17.7	3.4	16.8	4.6		
	18.7	2.7	18.2	3.4		
	17.0	4.1	18.1	3.0		
Means	17.2	3.9	17.8	3.5	+0.6	—0.4
			Weighted means of differences		+0.2	+0.2

almost the same as the order of increasing carbon-dioxide content. Explanatory notes are given regarding site and soil conditions at the time of sampling in each case.

Conclusions.—(a) Variation of soil-gas composition with depth.

The data provide little information regarding the variation of oxygen and carbon-dioxide concentration with depth at this site. The method used for gas sampling is apparently unsuitable for application to compact or very wet soil whose air-space is less than, say, 5 or 6 per cent. of the total volume of soil. On those occasions when deep samples could easily be procured, their composition was not greatly different from that of soil-gas taken from the surface 4-inch layer.

(b) Variation of soil-gas composition with site.

No consistent differences in soil-gas composition appear to occur between samples collected in slight depressions and those collected at the summits of small mounds, nor between samples from filled-in mulch-trenches and samples from undisturbed soil. On one occasion (No. 11, 15th December), when the soil was very wet, a gas sample procured from the 4 to 8-inch layer of a filled-in mulch-trench showed a relatively high concentration of oxygen and a low concentration of carbon-dioxide. No corresponding sample could be obtained from an undisturbed site on this occasion, but it is probable that, had this been possible, the soil-gas would have shown a similar composition to that of samples previously collected under wet conditions from compacted soil (for example, on 17th November), which showed very low concentrations of oxygen and high concentrations of carbon-dioxide.

(c) Variation of soil-gas composition with weather.

The composition of the soil-gas occurring in the surface 4-inch layer changed in very striking manner during the week 17th to 24th November, 1939*, the concentration of oxygen increasing and that of carbon-dioxide decreasing rapidly as the soil dried out slightly (compare samples Nos. 9 and 10, collected on 17th November, with samples Nos. 3 and 5 collected on 24th November). It changed still further in the same direction after two months of real dry season weather (*see* sample

* During this week, no rain fell at all, and the gross soil moisture content of the surface 6-inch layer dropped from 29.5 to 27.9 per cent. (F.H.)

Table II

Variation in composition of Soil-Gas with Depth, Site and Weather ; River Estate ; Trinidad

(Soil-gas samples obtained by method of Russell and Appleyard)

(A) Description of Site

No. of expt.	Date of sampling	Moisture conditions in soil	Conditions at site of sampling
	1940		
(1)	1 March	extremely dry ...	undisturbed soil ; untrampled
	1939		
(2)	10 November	fairly moist	slight hollow ; loose soil
(3)	24 November	dry	slight hollow ; loose soil
(4)	8 December	dry	old mulch-trench ; crumbly soil
(5)	24 November	dry week before ...	slight mound
(6)	8 December	dry	undisturbed soil ; untrampled
(7)	10 November	fairly wet	slight mound ; compact
(8)	8 November	fairly wet	slight mount ; compact
(9)	17 November	fairly wet	slight mound ; compact
(10)	17 November	fairly wet	slight hollow
(11)	15 December	very wet after rain ...	filled-in mulch-trench

(B) Composition of Soil-Gas

	Surface 4-ins. layer (0-4 ins.)		Second 4-ins. layer (4-8 ins.)		Third 4-ins layer (8-12 ins.)	
	Oxygen (Per cent.)	Carbon-dioxide (Per cent.)	Oxygen (Per cent.)	Carbon-dioxide (Per cent.)	Oxygen (Per cent.)	Carbon-dioxide (Per cent.)
(1)	19.9	1.1	20.1	1.4	—	—
(2)	18.8	2.5	13.8	5.7	—	—
(3)	18.8	3.0	—	—	—	—
(4)	17.8	3.4	—	—	—	—
(5)	17.5	3.9	—	—	—	—
(6)	16.6	4.4	—	—	15.6*	3.9*
(7)	14.8	5.5	12.8	6.1	11.9	6.9
(8)	9.5	9.3	8.1	10.3	8.5	9.6
(9)	9.4	6.6	—	—	—	—
(10)	9.2	6.3	—	—	—	—
(11)	—	—	15.9	4.0†	—	—

* One successful attempt only on this occasion.

† Not possible on this occasion to obtain gas samples from undisturbed soil between mulch-trenches.

No. 1, collected on 1st March). A small diminution in soil moisture content during November almost doubled the concentration of oxygen in the soil-gas contained in the surface 4-inch layer, and it might justifiably be surmised that, at slightly higher soil moisture contents, the concentration of oxygen might be reduced to almost *nil*. Anaerobic conditions probably occur quite frequently at this site during continuous rainy weather when the soil is saturated with water (for example on 9th September, 1939,* *see* Part I, Table IV).

The relationship between carbon-dioxide and oxygen contents appears to be reciprocal (*i.e.* their sum is approximately constant) for gas samples collected during relatively dry weather, but comparable wet-weather samples show no such simple relationship.

* On this date, the gross soil moisture content of the surface 6-inch layer was 31.9 per cent., which is slightly above the value for sticky point moisture for this soil. (F.H.).

Comparison with results obtained elsewhere.

Some data for soil-gas composition in temperate (European) and tropical (Indian) regions are given in Table III.

It will be noticed that the soil-gas in all the typical cases cited for temperate conditions contains more oxygen and very much less carbon-dioxide than that procured from the cacao field at River Estate, Trinidad. The extreme values quoted, namely, 15.7 per cent. oxygen and 3.2 per cent. carbon-dioxide (for dunged arable land), and 16.7 per cent. oxygen and 3.3 per cent. carbon-dioxide (for grass land), are similar in magnitude to the values found at River Estate during a relatively dry spell in the rainy season (*e.g.* between 24th November and 8th December, 1939 : Table II ; Nos. 3, 4, 5, 6), which averaged 17.7 per cent. oxygen and 3.7 per cent. carbon-dioxide in the surface 4-inches of soil. During wet weather, the soil-gas at River Estate contained considerably less oxygen and more carbon-dioxide

Table III

Examples of Variable Composition of Soil-Gas: Temperate and Tropical Climates

Soil	Typical composition		Observed limits	
	Oxygen.	Carbon-dioxide	Oxygen	Carbon-dioxide
	(Per cent.)			
Atmospheric air	21.0	0.03	—	—
(A) Temperate Climate (Europe; E. J. Russell, "*Soil Conditions*", 1932)				
(1) Average soil-air	20.6	0.25	—	—
(2) Grass land	18.4	1.60	20.5-16.7	0.3-3.3
(3) Arable land—unmanured... ...	20.4	0.20	22.3-18.0	0.0-1.4
(4) Arable land—dunged ...	20.3	0.40	21.2-15.7	0.0-3.2
Arable land—uncropped, unmanured				
(5) Sandy soil	20.6	0.16	20.8-20.4	0.0-0.3
(6) Loamy soil	20.6	0.23	20.9-20.0	0.1-0.6
(7) Peaty soil	20.0	0.65	20.5-19.2	0.3-1.4
(B) Tropical Climate (Pusa, India; J. W. Leather, 1914)				
(1) Fallow land—unmanured 0-2 ft.	14.9	—	18.6- 9.2	—
2-6 ft.	13.5	—	17.8- 7.6	—
(2) Fallow land—dunged 0-2 ft.	13.6	—	14.7-11.4	—
2-6 ft.	14.9	—	17.8-13.2	—
(3) Fallow land—green-manured 0-2 ft.	11.7	—	11.9-10.1	—
2-6 ft.	11.5	—	12.5-10.0	—
(4) Arable land—cropped 0-2 ft.	6.4	—	13.8- 2.2	—
(5) Swamp rice land 0-2 ft.	0.5	—	1.0- 0.3	—

Table IV

Example of Seasonal Fluctuations in Soil-Gas Composition: Apple Orchard Soils; New York State

After Boynton and Reuther (*Proc. Amer. Soc. Hort. Sci.*, 1938, 36, pp. 1-6)

Depth (feet)	(A) Sandy-Loam				(B) Silty-Loam				(C) Silty-Clay			
	Air-space, 16 per cent. Highly productive				Air-space, 7 per cent. Fairly productive				Air-space, 5 to 1 per cent. Low productivity			
	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
	Volume per cent.				Volume per cent.				Volume per cent.			
	(A) Oxygen Concentration											
0-1 ft. ...	20.1	20.2	19.8	19.9	19.3	18.3	19.6	19.6	17.1	18.9	18.6	18.2
1-2 ft. ...	19.9	19.9	19.6	19.6	11.1	9.3	16.6	18.2	5.3	1.9	17.1	17.0
2-3 ft. ...	19.8	19.7	19.3	19.3	4.3	1.4	12.7	16.8	1.2	0.8	14.0	15.6
3-4 ft. ...	19.5	19.8	18.8	18.6	2.9	0.8	9.0	15.8	0.2	0.0	6.7	11.1
4-5 ft. ...	19.3	19.2	18.2	18.3	3.1	0.2	7.3	15.5	0.6	0.2	3.0	8.4
5-6 ft. ...	18.2	19.0	17.0	17.4	2.1	0.1	4.9	15.0	0.0	0.1	1.2	6.9
	(B) Carbon-Dioxide Concentration											
0-1 ft. ...	—	—	—	—	—	—	—	—	0.9	0.7	2.7	2.5
1-2 ft. ...	—	—	—	—	—	—	—	—	4.0	3.5	3.6	4.1
2-3 ft. ...	—	—	—	—	—	—	—	—	6.9	6.6	5.9	5.7
3-4 ft. ...	—	—	—	—	—	—	—	—	9.9	9.8	9.5	8.4
4-5 ft. ...	—	—	—	—	—	—	—	—	11.5	11.8	11.5	11.2
5-6 ft. ...	—	—	—	—	—	—	—	—	16.2	14.9	12.2	11.3

Periods :—

(*a*) November to January } —wet winter dormant season
(*b*) February to April }

(*c*) May to July: —dry spring and summer growing season

(*d*) August to October; —moist autumn ripening season

(Table II: Nos. 8, 9, 10), averaging 9.4 and 7.4 per cent. respectively. Certain analyses of soil-gas made in Germany (results not recorded in Table III) show values for oxygen as low as 13 per cent., and for carbon-dioxide as high as 11.5 per cent. within the surface 2-feet of soil, but such extreme values are exceptional.

For tropical conditions, the only previous data for soil-gas composition that are available appear to have been obtained by Leather at Pusa, India (5), and these are included in Table III. Most of Leather's values for oxygen concentrations (apart from the value for swamp rice soil) are as low as, or even lower than, the extreme values obtained for cacao soil at River Estate.

Perhaps the most comprehensive and significant series of observations yet made in connection with soil aeration studies are those recorded by Boynton and Reuther (4), who investigated in detail, during 1937 and 1938, the seasonal fluctuations in oxygen and carbon-dioxide contents of the soil-gas of three apple orchards situated in the State of New York. The soils of these orchards differed greatly. The first (A) was a highly productive sandy-loam, uniform in texture to below the 6-foot depth, and having a non-capillary pore-space of 16 per cent. by volume. The second (B) was a uniform silty-clay-loam of above the average producing capacity, having a non-capillary pore-space lying between 8 and 6 per cent., but the third (C) was a heavy silty-clay on which apple-trees were short-lived. The non-capillary pore-space of this soil was 5 per cent. down to 4 feet, and only one per cent. below that depth. The distribution of apple tree roots in these three contrasted soils was found to be closely related to the oxygen concentration in the soil-gas at different depths in the profile. Some extreme values for oxygen concentrations in the soil-gas of these three orchard soils, abstracted from Boynton and Reuther's graphs, are given in Table IV.

The highly-productive sandy-loam soil (A) is outstanding in that its oxygen content remained nearly constant and at a high value for all depths throughout the whole year, reaching a minimum of about 17 per cent. at the lowest depth during a few weeks only. On the other hand, the poor silty-clay soil (C) contained practically no oxygen at all below the 3-foot depth during half the year, and usually never more than 10 per cent. of oxygen, even when the soil had dried out during the summer. At the 1 to 2 foot depth, the oxygen content of this soil seldom exceeded 5 per cent. during the wetter half of the year, though it rose to higher proportions during the dry months. The only part of this soil which might be regarded as well aerated throughout the year is the surface one-foot layer.

The silty-loam soil (B) is intermediate between the other two, as the data in Table IV clearly indicate. Here, the upper 2-foot layer exhibited good aeration throughout the year, but the layers below the 2-foot level were less satisfactory.

It is noteworthy that the values for oxygen content of gas samples collected from the surface one-foot layer of each of the apple orchard soils are considerably greater than those recorded in Table II for the River Estate cacao soil, especially for samples collected during wet November weather.

Carbon-dioxide contents of soil-air are given by Boynton and Reuther for their apple orchard soils only in the case of the poor silty-clay (C). The recorded data (Table IV) show values greater than about 10 per cent. in all layers below the 3-foot depth for the whole of the year. The range of fluctuation, however, is very much less for carbon-dioxide content than for oxygen content for all depths. The carbon-dioxide figures for the surface foot layer of the poor silty-clay soil (C) are considerably less than those for the River Estate cacao soil, especially for samples collected during wet weather. No precise reciprocal relationship between the carbon-dioxide and the oxygen contents of the soil-air is revealed by Boynton and Reuther's data. This fact may be regarded as a manifestation of greatly impeded gas diffusion within the profile.

In attempting to compare Boynton and Reuther's results with ours, an important difference between the growth conditions affecting cacao trees in Trinidad must be kept in mind, for, whereas the main growing and fruiting season of the apple tree is the summer and autumn when the rainfall is relatively light and discontinuous, that of the cacao tree in Trinidad is the wet season, when the rainfall is very heavy and frequent. On the other hand, the apple tree is dormant during the wettest part of the year (late autumn and winter), whereas the cacao tree is least active during the driest part. Thus, at poorly-drained and badly-aerated sites such as that occupied by the poor apple orchard on silty-clay soil in New York State, least aeration occurs during the period when the trees are dormant, whereas, in the case of unsatisfactory sites growing cacao in Trinidad, the worst conditions of soil aeration are likely to occur when the tree-roots and soil micro-organisms should be most actively respiring, and the cacao crop ought to be setting. Hence, such marked fluctuations in oxygen supply as are likely to occur at these sites must greatly affect the growth and behaviour of cacao, so that high production of pods might be expected only from fields whose soil is freely drained and exceptionally well ventilated.

The evidence adduced by pore-space measurements and gas analysis at River Estate indicate that, although the soil-type in which cacao is here growing is considered to be a relatively free-draining type, the conditions of aeration are frequently unsatisfactory, especially during periods of continuous rains. Apart from small air-space volume during the wet season (except in the shallow surface layer), the concentration of oxygen in the soil-gas is likely often to fall below 10 per cent. and that of carbon-dioxide to rise above 6 per cent.,

values which may be regarded as outside the limits of the "cardinal concentrations" requisite for root activity and the formation of new roots.*

(B) SOIL AIR COMPOSITION AT OTHER CACAO SITES

By H. A. Thompson, B.Agr., B.Sc. (Belfast)
(*Former Post-Graduate Student*)

In continuation of the investigations carried out at River Estate by Dr. H. Vine which have been described in the last section, arrangements were made for the periodic sampling during 1939-40 of soil-gas at four widely-separated sites where cacao is growing under different environmental conditions (6). The sites unfortunately were not truly representative of the chief cacao soil-types of Trinidad; restrictions in time and travelling prohibited a better selection, and only one of the numerous important clay-types of cacao soil could be included.

Two of the sites, (B) and (C), were on the River Fine Sand soil-type, one at River Estate near the site of Dr. Vine's investigations, the other at La Reconnaissance Estate (L.R.C.), in a Northern Range valley 15 miles east of River Estate. The third site (A) was on a similar fine sandy soil, namely, Maracas Sand (Detrital Phase), comprising a plot of the Botany Section of the College. The fourth site (D) was on a compact heavy river alluvial soil-type, namely, Sangre Grande Clay-Silt, at Las Hermanas Estate, San Rafael.

Such yield data as are available indicate that the order of productivity of cacao for the four sites is; La Reconnaissance (highest); River Estate (not quite so high); College (much lower), and Las Hermanas (very low).

Experimental Work

The method used for soil-gas sampling was Boynton and Reuther's "sampling-well" method (4). At each site, pairs of sampling wells (consisting of short pieces of glass tubing of dimensions 20 by 75 mm. filled with glass wool and open at the base) were sunk permanently in the soil at five depths, namely, 4, 10, 18, 36 and 48 inches. Narrow copper connecting tubes led above the ground surface, so that samples of gas that collected in the wells could be withdrawn when required for transportation and analysis in the laboratory.* Each of the four sites was visited fortnightly over periods covering about four months of the wet season and five of the dry. Altogether, some 230 gas samples were collected and analysed, many in duplicate.

Little trouble was experienced in withdrawing gas samples at the three sandy sites, but the clay site presented many difficulties in procuring suitable samples. The clay soil at this site cracks deeply in dry weather, and becomes soggy in wet weather. Soil cracking rendered many of the wells useless after they had functioned satisfactorily for a time, and stickiness when wet caused the soil to become impervious, so that very few gas samples could be procured during the rainy season, even when considerable suction was applied. Only on five occasions in the dry season and on two occasions in the wet season (during early December) could reliable samples be obtained at this clay site, and even then, only at the shallower depths.

Soil moisture data and physical soil constants for each of the four sites were abstracted from the records of ecological investigations that were being simultaneously carried out by the College Chemistry Department, so that the contents of "available" moisture† in the soils at the times of gas sampling were known. Typical values of soil constants are set out in Table V; porosity data were calculated as explained in the last article (Part I).

The experimental values for gas composition are not here reproduced in full, but average values for "dry" and "wet" soil conditions have been calculated; they are presented in Table VI.

The figures in Table VI are means of six to nine values for oxygen and carbon-dioxide contents, except those in brackets, which are means of only two to four values. "Dryness" and "wetness" was gauged by reference to data for available soil moisture, values below about 10 per cent. being regarded as denoting dryness. Most of the "wet" values naturally refer to the rainy season, but moist soil conditions were maintained to different extents at the different sites during part of the dry season. Thus, at the College site, the soil began to dry out during the second half of January and at the River Estate site during the second half of February, whereas at the La Reconnaissance site, dry conditions did not really set in until the first half of April, allowing only four determinations of dry season soil-gas composition, which, however, gave remarkably consistent results.

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* The following values have recently been suggested by Boynton (*Science*, 1938, p. 569) for cardinal concentrations of oxygen for root activities of the *apple tree*.

Above 12 per cent. oxygen	:	new roots form.
„ 10 „	„	water absorption proceeds.
10 to 5 „	„	root tips grow.
3 to 0.1 „	„	roots merely subsist.

For *cacao*, H. Vine has obtained preliminary evidence (2) that 9 per cent. oxygen marks approximately the lower limit for satisfactory root activity.

* A portable Haldane gas analysis apparatus was not available at the time of these experiments; the use on the spot of such equipment would have expedited the work considerably. (F.H.).

† By "available" soil-water is meant that above the wilting coefficient, which may be determined roughly by the use of standard formulae applied to soil-moisture constants. (F.H.).

Table V

Physical Soil Constants for four different Cacao Sites.

Depth layers	Content of coarse and fine sand. (per cent.)	Index of Texture*	Total pore-space (volume per cent.)	Capillary pore-space† (volume per cent.)	Non-Capillary pore-space‡ (volume per cent.)
SITE (A) : COLLEGE					
0- 6 ins. ...	47	19	47	28	19
6-12 ins. ...	47	21	46	30	16
12-18 ins. ...	49	16	40	24	16
18-24 ins. ...	54	14	39	23	16
24-36 ins. ...	61	11	38	18	20
SITE (B) : RIVER ESTATE					
0- 6 ins. ...	53	19	49	26	23
6-12 ins. ...	51	20	44	31	13
12-18 ins. ...	49	20	36	30	6
18-24 ins. ...	54	15	36	26	10
24-36 ins. ...	51	17	41	28	13
SITE (C) : LA RECONNAISSANCE ESTATE					
0- 6 ins. ...	55	26	47	36	11
6-12 ins. ...	51	18	40	30	10
12-18 ins. ...	54	20	40	32	8
18-24 ins. ...	59	12	38	20	18
24-36 ins. ...	62	8	40	18	22
SITE (D) : LAS HERMANAS ESTATE					
0- 6 ins. ...	0	50	57	50	7
6-12 ins. ...	0	44	55	50	5
12-18 ins. ...	0	42	49	49	0
18-24 ins. ...	0	38	46	46	0
24-36 ins. ...	0	36	44	44	0

* Index of Texture = Sticky-point moisture content *minus* one-fifth coarse and fine sand content.
† Capillary pore-space = Index of Texture *multiplied by* apparent specific gravity of dry porous soil.
‡ Non-capillary pore-space = Total pore-space *minus* capillary pore-space.

At the Las Hermanas (clay) site, only two "wet" gas samples could be procured, and five "dry" samples. Few of the values for this clay site are really representative, because of the difficulties of gas sampling and the fact that the soil dried out extremely slowly, so that the difference between wet and dry conditions during the course of the experiment was not well demarcated.

Conclusions :—

(1) The gas analysis values in Table VI for the River Estate site, where comparable, are of the same order of magnitude as those obtained previously by Dr. Vine (*see* Table II).

(2) If we accept the value 10 per cent. as denoting the lower limit of oxygen content of soil-gas favourable to root activity in cacao, then it would appear that satisfactory conditions prevailed throughout the whole year at each of the four sites for soil layers above the 18-inches depth.

(3) Under *dry soil conditions* (*i.e.* available soil mositure less than about 10 per cent), each of the soils down to the full depth of sampling (4 feet) seems to have contained air sufficiently rich in oxygen to satisfy the needs of actively-growing cacao roots.

(4) Under *wet soil conditions* however (*i.e.* available soil mositure above 10 per cent.), the average oxygen content at two of the sites (River Estate and La Reconnaissance Estate) was definitely insufficient in the layers below the 18-inch depth, but at the College site it was highly satisfactory to the full depth of sampling. The data for the Las Hermanas Estate (clay) site are unreliable, but, judging by the fact that wet season samples could only be procured at the very end of the year when they showed low oxygen contents for layers below the 18-inch depth, it is likely that the composition of the soil-gas within this zone was unsatisfactory for most of the wet season, and possibly also for much of the dry season as well. The physical soil constants (Table V) indicate that this soil contained little or no non-capillary pore-space at the time of soil sampling.

(5) Doubtless there were spells in the wet season at each site when the soil-gas contained an insufficient concentration of oxygen. Indeed, the detailed results include several values less than 10 per cent. in magnitude for wet-season samplings at the River Estate and at the Reconnaissance Estate sites, even for the surface 4-inch

Table VI

Composition of Soil-Gas at four different sites growing Cacao in Trinidad

(*Soil-gas samples obtained by method of Boynton and Reuther*)

Note :—Values are averages for the different depths

Gas-sampling depth (inches)	Site (A) College		Site (B) River Estate		Site (C) L.R.C. Estate		Site (D) Las Hermanas Est.	
	Fine sandy soils						Silty-clay soil	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
	Volume per cent.		Volume per cent.		Volume per cent.		Volume per cent.	
			(I) Oxygen Concentration.					
4 ins. ...	18.0	20.6	13.7	20.6	14.9	(20.8)	(15.9)	(18.7)
10 ins. ...	16.4	20.0	12.7	19.8	13.4	(20.0)	(17.8)	19.4
18 ins. ...	15.3	19.5	12.2	18.8	11.1	(19.4)	(12.2)	18.0
36 ins. ...	14.3	18.5	7.6	17.3	6.0	(17.0)	(?)	(8.6)
48 ins. ...	14.1	17.7	7.8	16.4	5.7	(15.8)	(3.1)	—
			(II) Carbon-Dioxide Concentration					
4 ins. ...	2.8	0.5	6.5	0.5	4.2	(0.2)	(3.6)	0.8
10 ins. ...	3.0	1.1	8.5	1.6	5.5	(0.8)	(3.0)	1.7
18 ins. ...	4.2	1.7	9.7	3.2	6.3	(1.4)	(5.3)	3.8
36 ins. ...	4.5	3.4	10.0	5.2	7.3	(3.4)	(14.3)	7.6
48 ins. ...	5.5	3.7	9.6	6.8	3.6	(4.2)	(17.5)	—
Average contents of "available" soil moisture during sampling periods								
0-6 ins. ...	13.0	2.5	16.8	11.3	21.1	(9.5)	(6.6)	(2.7)
6-12 ins. ...	12.4	4.6	15.6	11.2	16.7	(10.1)	(6.1)	(2.0)
Wilting coefficient values (per cent. oven-dry soil)								
0- 6 ins. ...	12.0		10.6		14.2		27.5	
6-12 ins. ...	10.8		10.5		11.7		26.0	
Sampling periods :—								
Wet ...	20 Aug.-7 Jan.		29 Oct.-28 Jan.		24 Oct.-13 Feb.		2 Dec.-6 Feb.	
Dry ...	12 Jan.-22 Apr.		11 Feb.-27 Mar.		13 Mar.-27 May		20 Feb.-5 Mar.	

Note.—Figures in brackets are means of 2 to 4 determinations ; others are means of 6 to 9 determinations.

layer, as well as for layers below. On no occasion, however, was a value less than 10 per cent. recorded for the College site.

(6) On some occasions, especially in the wet season, within the lower soil-layers, carbon-dioxide concentrations reached relatively high values,* notably at the River Estate site, implying the possible incidence of toxic conditions. Values obtained on these occasions furthermore showed no simple reciprocal relationship between oxygen contents and carbon-dioxide contents, implying restricted gas circulation or tardy diffusion within the soil profile.

(7) Marked differences in soil moisture status were shown between the four sites (Table VI). At the College site, the content of available soil mositure was relatively low, even during the wet season, and it fell to the wilting point by the middle of February, where it remained until the rains broke in May. By contrast, the available soil moisture contents at the other two sandy sites, because of their superior topographical position and protection from winds, stayed at a relatively high level ; they seldom fell below 10 per cent. throughout the year, and never once reached the wilting point.

* Most authorities seem to be agreed in attributing the ill effects of unsuitable soil atmospheres to a shortage of oxygen rather than to toxic concentrations of carbon-dioxide. Some accept the value 6 per cent. of carbon-dioxide as marking the upper limit of tolerance by living plant-roots, though direct experimental evidence in support of this contention appears to be lacking. (F.H.).

(8) The available moisture content of the clay soil at Las Hermanas, judging by previous records, usually maintains a relatively high level (up to 15 or 20 per cent.) during the wet season, but the soil may begin to dry out any time in January to March, though it seldom dries out as far as the wilting point. The data in Table VI for the "wet" period refer only to December and January when the soil was already drying out, and it is likely that, during the main part of the rainy season, the composition of the soil-gas at this site is quite different from that recorded in the "wet" column in Table VI. Values in the "dry" column, on the other hand, are probably more typical; they indicate the effect of cracking on the ventilation of this clay soil.

(9) It is evident that further investigations are needed on clayey types of cacao soil occurring in Trinidad, and it is suggested that examples having coarser texture and lower clay content should be examined by the same methods as those described in this and the previous article.

(10) The evidence herein presented on the whole indicates that the La Reconnaissance site is the most satisfactory of the four as regards aeration and moisture status, and the Las Hermanas site (clay soil) the least satisfactory. The River Estate site is more satisfactory, especially with regard to moisture status, than the College site. These differences appear to be reflected in the variation in productivity of cacao at the four sites.

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REVIEW

GAS PRODUCERS FOR MOTOR VEHICLES AND THEIR OPERATION WITH FOREST FUELS

By I. KISSIN, Imperial Forestry Bureau, Technical Communication No. 1, 1942, pp. 37, price 3*s*.

This publication contains a careful, comprehensive review in relatively non-technical language of the use of producer-gas and mixed producer- and water-gas as fuel for engines previously employing petroleum products. This subject is of considerable interest to-day in those parts of the world in which petroleum is not readily available.

For those dominions and colonies which have large reserves of timber convertible into suitable charcoal the producer-gas units provide a solution to the transport difficulties caused by the difficulty of obtaining, and the high cost of, petrol and heavy oil fuel. The loss of power on converting a petrol engine to a gas engine, may be overcome in various ways, *e.g.*, by fitting a supercharger. Even tractors may be run on producer-gas though as these are usually run more nearly at their power limit than transport vehicles higher powered tractors would generally be required for comparable work.

As fuel, charcoal gives the best performance in producer-gas-driven vehicles in acceleration and hill climbing while anthracite gives the highest mileage. Wood may be used as fuel but is bulky and requires additional devices for the removal of tars and moisture. In general the fuel cost when using charcoal is very much less than with liquid fuel even when the producer-gas mixture is occasionally boosted with petrol. Saving is also effected on lubricants. In fitting a vehicle with a producer-gas generator there is the initial cost, upkeep and also the extra wages of more highly skilled hired drivers to be considered but in general even under normal conditions a considerable saving in running costs is effected where the cost of petrol is 2/- per gallon or more.

In many, probably most, colonies charcoal is prepared by the "primitive" method of burning wood in pits. The charcoal so produced is too dirty for use in producer-gas generators. Before a large introduction of producer-gas-driven vehicles becomes possible it will be necessary to encourage the use of kilns and the most suitable local woods to give a cleaner and more uniform product.

In a number of countries especially Germany and the U.S.S.R. the use of producer-gas as a vehicle propellant has long been encouraged and a considerable number of vehicles using this gas mixture were in use during the first year of the war. It must be felt by all who read this review that it is very unfortunate that encouragement in the Empire for research and development of producer-gas generators came so late. The British Emergency unit was evolved from the work of a Committee set up in 1937: Australia and South Africa appointed committees to stimulate and co-ordinate research in 1939 and 1940 respectively. The result of this lack of foresight is that while vast areas of the Empire are eminently suitable for vehicles using producer-gas as fuel and while cheap and efficient generator units can be made, the materials for their manufacture are now almost unobtainable.

H. R. B.

CHEMICAL NOTES

(Compiled by the College Department of Chemistry and Soil Science)

Water Reserves In Brazilian Forest Soils

This feature of some of the soil in the vast forest areas of Brazil is emphasized by Felix Rawitscher in his transpiration studies by rapid weighing methods under field conditions (*Anais da Academia Brasileira de Ciencias*, 14 (1), 1942). The soil depth in tropical and sub-tropical regions may reach a maximum of 15-20 metres, and considerable water reserves may be accumulated in the deeper layers of soil. During the dry period of the year these furnish water, not only to sources and streams, but also to the deeper plant roots. Large zones of humid forests in the interior of San Paulo live on these reserves during the dry period. The author suggests that the high transpiration rate of extensive humid forests must have a considerable influence on the humidity of the climate.—(*Nature*, Vol. 150, No. 3797.)

* * *

The Functions of Roots

Intake from nutrients through roots takes place in three ways:—(1) direct absorption of anions and cations through the finer roots and root-hairs; (2) absorption or exchange of nitrogenous compounds from nodules attached to the roots of many leguminous plants; (3) indirect absorption through the medium of fungi which, together with the roots, form what are known as mycorrhizae. Recent knowledge about roots has given new perceptions about their extent. T. K. Pavlychenko has measured the roots of single prairie grasses grown free from competition of other plants, and has recorded more than three hundred miles of root belonging to a single plant three years old, while a single plant eighty days old had fifty-four miles of roots of first and second order alone. A young plant may have a net gain of the order of one mile of root daily. Roots are neither permanent, as a rule, nor static. The finer roots of a living plant are constantly being shed, and thus are taking part in the cycle of decomposition in the soil. Within a few weeks, apple rootlets, for example, have been observed to grow and decay, fresh ones being formed meanwhile in the same region of soil.

There is a balance between the amount of root and the amount of top. By cutting the tops of a plant—say, by mowing the lawn—the roots are also trimmed.

A closely cut lawn suffers during a drought because the diminished roots are not able to reach the soil moisture in the deeper layers.

Roots are not merely absorbing organs; they are also reserve organs. The relation between tops and roots has important practical consequences, since if perennial forage plants and grasses are cut or grazed too closely in late autumn they will not be in a good condition to survive the winter or to make early growth in spring, on account of the lack of sufficient reserves in the roots. Nitrogenous manures applied in spring are no substitute for adequate over-wintering root reserves.

Leguminous plants may possibly excrete nitrogen fixed by the aid of their associated nodule bacteria, and may thus act as nitrogen "foster-mothers". The dynamics of the plant include several modes of return of absorbed material to the soil. The most obvious in perennial plants is leaf-fall.—(Abstracted from an article by Dr. Hugh Nicol, in *Nature*, Vol. CL, No. 3792, 1942.)

* * *

The Physiological Rôle of Selenium in Plants

From the point of view of essentiality and uptake, one of the most interesting chemical elements is selenium. Its physiological rôle has been recognized only in the last decade, owing to the investigation of seleniferous soils. These soils have only a small selenium content, but cover vast areas in North America. Marco Polo recorded poisoning of animals in China which has since been shown to be referable to a seleniferous soil. A similar condition in Ireland remains unexplained.

In their reactions to selenium, plants may be divided into four groups: (1) those which require selenium, (2) those which can tolerate large amounts in their tissues, (3) those which can tolerate small amounts but are poisoned by large amounts (these include crop plants such as wheat), and (4) those which practically exclude it. The last group comprise some native prairie grasses. The first group is formed by some species of the botanically varied genera *Astragalus*, *Oonopsis* and *Stanleya*; for these selenium is an essential element, and the concentration in the dry matter and in the seed may surpass 3,000 parts per million. Recently an amino-acid complex containing both selenium and sulphur has been isolated from grain and from *Astragalus*.

Plants for which selenium is essential, such as certain species of *Astragalus*, will, of course, grow naturally only on seleniferous soils (the converse does not hold). Hence they serve as an interesting introduction to the subject of "indicator" plants—that is, plants which by their presence or mode of growth indicate soil conditions.—(Abstracted from an article by Dr. Hugh Nicol, in *Nature*, Vol. CL, No. 3792, 1942.)

* * *

Green Manuring of Lowland Rice

According to an article in the *Meded Alg. Proefsta. Landbouw* 50, 1941, pp. 28 (Du.e.) improvement of nutritive value and considerable increase of yield were obtained through green manuring, though the effect varied with the variety of rice. The vegetation period of rice was shortened, indicating that the green manure supplied nutrients other than nitrogen. *N. Crotalaria* spp. were found best as green manure.